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FACULTY OF ENGINEERING
Mechanical Power Engineering Department

Refrigeration and Air Conditioning — 4th Year (Power)

Revision

1. A refrigeration system follows the reversed Carnot cycle between the temperature limits of 0 °C and 30 °C. Find:
   a) The coefficient of performance when it works as a refrigerator and as a heat pump. What would be the coefficients of performance if the heat-sink temperature was increased to 40 °C?
   b) The power in kW required for a refrigeration load of 58.15 kW in both cases?
   c) The rate of heat rejection. in kW, in both cases?

2. A new refrigerator is said to require 1.103 kW for a duty of 2.791 kW when working between the temperature limits of −15 °C and 30 °C. Can this be true?

3. A heat pump system is used to serve a heating load of 116.3 kW at a temperature level of 40 °C. If the heat-source temperature is 0 °C, determine the power-input requirement in kW assuming that the relative efficincy is 70 %.

4. A system works on the reversed Carnot cycle between a high temperature of 40 °C and a low temperature of
   (i) −50 °C (ii) −25 °C (iii) 0 °C (iv) 20 °C
   Determine the C.O.P of the system as a refrigerator and as a heat pump. Represent the results on a suitable diagram. Repeat the results if the high temperature is lowered down to 30 °C. Comment on the results.

5. A refrigeration system follows the reversed Carnot cycle between a heat source and sink temperatures of T_1 and T_2 respectively. It is possible either to raise T_1 or reduce T_2 by two degrees. Determine which of the two alternatives is more effective for increasing the C.O.P

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Refrigeration and Air Conditioning 4th Year (Power)

Single-Stage Vapour-Compression Systems.

1. In a theoretical single stage ammonia vapour compression system, liquid leaves the condenser at 2 MPa and 40 °C. Evaporator pressure is 0.15 MPa, vapour leaves the evaporator at −18 °C. The system produces 15 tons of Refrigeration. Determine:
   a) The coefficient of performance.
   b) The piston displacement in m^3 per sec. (assuming volumetric efficiency of 100 %).

2. A vapour-compression refrigeration machine is used for ice making. The evaporation and condensation temperatures are −8 °C and 45 °C respectively. The cycle refrigeration efficiency is 40 %. Water is available at 30 °C and ice is produced at −4 °C. The combined electric-motor and belt-drive efficient is 81 % and the compressor mechanical effciency is 80.4 %. If the daily electric-energy consumption is 1.8×10^7 kJ, calculate the daily output in tons of ice.

3. A mechanical vapour-compression heat pump is to be used for heating a building with a design load of 58.15 kW. Water at 10 °C is available as a heat source and the air supplied to the building is to be at 38 °C. A 5 °C differential is necessary between condensing refrigerant and supply air and between evaporating refrigerant and heat source. If the relative efficiency is 70 %, calculate the brake power in kW required to meet this heating load. ($\eta_m = 0.9$)

4. A mechanical vapour-compression refrigerator has a capacity of 5 tons. It follows a refrigeration cycle with a C.O.P of 2.5. It is assumed that no heat exchanges occur along the interconnecting piping between the system components. The compression is adiabatic. The machine is fitted with a water-cooled condenser, and the water temperature rise in it is 7 °C. Estimate the required flow rate of cooling water in m^3/sec.

5. Catalogue data for a refrigerant-12 compressor with a displacement of 0.0283 m^3/sec., shows the capacity to be 13.7 T.R. and brake power 10.371 kW; when the suction conditions are −18 °C and 0.3 MPa and the condensing temperature is 35 °C. The refrigerant leaves the condenser as saturated liquid. Calculate the actual volumetric efficiency and the adiabatic compression efficiency of the compressor (η_m = 90 %).

6. If the electric power required to drive a freon-12 refrigerating machine costs 17 millimes per kWH, and the water consumption costs 12 millimes per cubic meter, find out whether a rise in the condenser cooling water temperature of 5 °C or 18 °C would be more economical in the operating expense of the machine when working at an evaporation temperature of −12 °C and with cooling water at 21 °C, and allowing 84 % for the mechanical efficiency of the compressor, 85 % for motor efficiency and 90 % for belt efficiency. Assume a simple saturation cycle.

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7. A single-stage, freon 12, refrigerator operates at an evaporating temperature of -5 °C. Vapour leaving the evaporator to the compressor had a superheat of 5 °C. A long suction line connects the remotely-located evaporator to the compressor. Due to aging, the thermal insulation of the suction line deteriorated, and a new vapour-temperature rise of 20 °C takes place along the suction line. Calculate the effect on the refrigeration capacity.

8. A single-room cold store has a storage capacity of 1000 tons of a certain product. The room has a square floor area. The storage density is 3.2 m^3/ton. The reach of the fork-lift trucks limited the ceiling height to 8 m. The room is maintained at a temperature of 0 °C and the average ambient-air temperature is 30 °C.

The refrigeration plant works with ammonia and follows a simple saturation cycle between evaporating and condensing temperatures of -10 °C and 40 °C respectively. The compressor is driven by an electric motor through a belt drive. The mechanical, drive, and motor efficiencies are 0.93, 0.98, and 0.95 respectively. Electric energy, at the store location, costs 30 mill/kWh. The overall coefficient of heat transfer of the store envelope is 2.326×10^{-4} kW/m^2 °C. It is proposed to increase the thermal insulation of the exterior surfaces (except the floor) by adding 0.1 m of a thermal insulating material having a thermal conductivity of 2.908×10^{-5} kW/m °C. The cost of this material is 50 LE/m^3.
The remainder of the expected life of the plant is 10 years and the daily operating period of the refrigeration equipment is considered to be 20 hours. Determine whether this proposal is economically feasible or not.

9. It is wanted to choose a compressor for a creamery installation operating under the following conditions; capacity of 18.5 T.R., condensing pressure of 1.5 MPa, ammonia liquid leaves condenser at saturated conditions, ammonia liquid enters the expansion valve at 24.5 °C, evaporating temperature of -12 °C, vapour leaves evaporator at saturated conditions, vapour is superheated 11 °C in compressor suction line. A compressor of the following characteristics is available; 4 cylinders, vertical, reciprocating single acting, single stage, water jacketed compressor with a maximum R.P.M of 600, cylinder diameter is 0.1 m and stroke of 0.12 m. The following supplemental assumptions to allow for further calculations are taken; clearance ratio of 4 %, pressure drop in suction valve is 0.03 MPa, vapour is superheated 8 °C in cylinder on intake stroke after passing the suction valve, Polytropic compression with n=1.27, pressure drop in discharge valve is 0.05 MPa, compressor mechanical efficiency is 80 %.
a) Determine if the available compressor can be used and at what R.P.M should it operate?
b) Estimate the kW required to drive the compressor?

10. A freon-12 refrigerating machine is used in a meat factory to cool 10 tons of meat from 38 °C to -10 °C in 12 hours. The compressor used is single stage and has 8-cylinders and runs at 900 R.P.M. The machine is fitted with a liquid-suction heat exchanger. Given the following data:
Suction and delivery pressures are 0.15 and 0.8 MPa, respectively.
The liquid is saturated at outlet from the condenser.
Temperature at outlet from the evaporator = - 8 °C.
Temperature at compressor suction valve = + 3 °C.
There is a pressure difference due to suction and discharge valves = 0.01 MPa. Heating in the compressor during suction raises the

Specific heat of meat above freezing = 2.931 and below freezing = 1.675 kJ/kg ^oC.
Latent heat of freezing of meat = 209.35 kJ/kg and freezing temperature = − 1.5 ^oC.
Calculate the following:
a) Power needed for the compressor if mechanical efficiency = 0.85.
b) Bore and stroke of the compressor if L/D = 1.2, clearance ratio = 3 %.
c) Coefficient of performance of the refrigerating machine and the relative efficiency of the cycle.

11. A freon-12 refrigerating machine is required to cool 5.6×10^{-3} m^3 of milk per sec. from 26 ^oC to 5 ^oC. The compressor used has six cylinders of 0.15 m bore and 0.20 m stroke and runs at 760 R.P.M. The machine is fitted with liquid-suction heat exchanger. The following data is given:
Compressor suction pressure = 0.25 MPa.
Compressor delivery pressure = 0.7 MPa.
Temperature at compressor suction = + 8 ^oC.
Temperature at compressor discharge = 52 ^oC.
Temperature at condenser outlet = 26 ^oC.
Temperature at evaporator outlet = − 1 ^oC.
The specific gravity of milk is 1.03 and its specific heat = 3.873. If the combined mechanical and motor efficiency = 65 %, calculate:
a) The power of the electric motor in kW.
b) Compressor isentropic and volumetric efficiencies.
c) C.O.P of the machine and the relative (refrigeration) efficiency.

12. A R-12 four cylinders, 0.05 m diameter by 0.06 m stroke, compressor runs at 1500 R.P.M. The condensing temperature is 30 ^oC with 6 ^oC subcooling and the evaporating temperature is −2 ^oC with no superheating. It is proposed to instal a liquid-suction vapour heat exchanger to prevent condensing of atmospheric moisture on the suction pipe when the surrounding atmospheric condition is 36 ^oC dry bulb temperature and 26 ^oC wet bulb temperature; draw a diagramatic arrangement of the plant; and determine:
a) Weight of refrigerant handled by the compressor, allowing a volumetric efficiency of 84 %.
b) The capacity of the plant in T.R.
c) Condition of refrigerant on leaving the heat exchanger, at suction valve of the comperssor.
d) %age effect which the heat exchanger has on the capacity of the plant.
e) %age effect on the C.O.P.

13. A single-stage freon-12 refrigerator works on the simple saturation cycle and has an air-cooled condenser. The compressor has a clearance ratio of 4 %. The evaporation temperature is −5 ^oC and the compressor discharge temperature is 50 ^oC. The rated capacity under these design conditions is 20 tons. During a hot spell the condensing temperature increased to 55 ^oC. Calculate the refrigeration capacity under this severe condition. With the condensing temperature at 55 ^oC, determine the evaporating temperature at which the refrigeration capacity would diminish to zero.

14. An ammonia vapour-compression brine-cooling plant is to be designed for a refrigeration capacity of 30 tons. The available cooling-water temperature and the required brine temperature

necessitate a condenser pressure of 1 MPa and a brine cooler pressure of 0.15 MPa. The following temperatures will exist at the points designed: compressor discharge 100 ^oC, compressor suction −14 ^oC, leaving condenser 16 ^oC, at expansion valve 20 ^oC, and leaving evaporator −20 ^oC. Pressure drops in suction and discharge valves are 0.05 and 0.1 MPa respectively. A two-cylinder single-acting compressor is to be used at a mean piston speed of 2 m/sec. Mechanical efficiency is 0.88. Ratio of stroke to bore is 0.9. Clearance factor is 5 percent. Calculate:

a) Indicated and brake power of compressor.
b) Heat rejected from compressor per sec.
c) Heat rejected in condenser per sec.
d) Bore, stroke, and speed of compressor.
e) C.O.P of the machine.

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Mechanical Power Engineering Department

Refrigeration and Air Conditioning 4th Year (Power)

Compound Vapour-Compression Systems

1. The following conditions apply to 100 ton, ammonia compound vapour compression system with water intercooler. Condenser pressure is 1.5 MPa, evaporator pressure is 0.15 MPa, intercooler pressure is 0.5 MPa, and volumetric efficiency as: low pressure = 85 %, high pressure = 78 %. Assume pressure drop through compressor valves as follows: low pressure suction = 0.015 MPa, low pressure discharge is 0.035 MPa, high pressure suction = 0.03 MPa, high pressure discharge = 0.07 MPa. Ammonia may be cooled to 32 °C in intercooler, and sub-cooled liquid from condenser is at 30 °C, suction temperature is −18 °C. Temperature leaving the brine cooler = − 21 °C. Low pressure compression is adiabatic. High pressure compression has an index (n) of 1.27. Both cylinders are double acting. Calculate: (Assume $\eta_c = 100\,\%$ of L.P.C)
   a) Ammonia to be circulated per second.
   b) Indicated power of high pressure cylinder.
   c) Indicated power of low pressure cylinder.
   d) Heat rejected to intercooler (kW).
   c) Piston displacement of low pressure cylinder and high pressure cylinder, m^3/sec.
   f) Coefficient of performance based on I.kW.

2. a) A cold-store for frozen fish is to be maintained at a temperature of − 7 °C. The estimated heat load for the store is 174.45 kW, and is to be performed by an ammonia brine refrigerating plant working at a condenser pressure of 1 MPa, and at an evaporator pressure of 0.25 MPa. If a 4-cylinder compressor running at 600 R.P.M is used and having a compression efficiency of 80 %, volumetric efficiency of 75 %, and mechanical efficiency of 80 %. Calculate:
      (i) The brake power in kW of the compressor.
      (ii) The bore and stroke of the compressor.
      (iii) The C.O.P of the plant, and its relative thermodynamic.

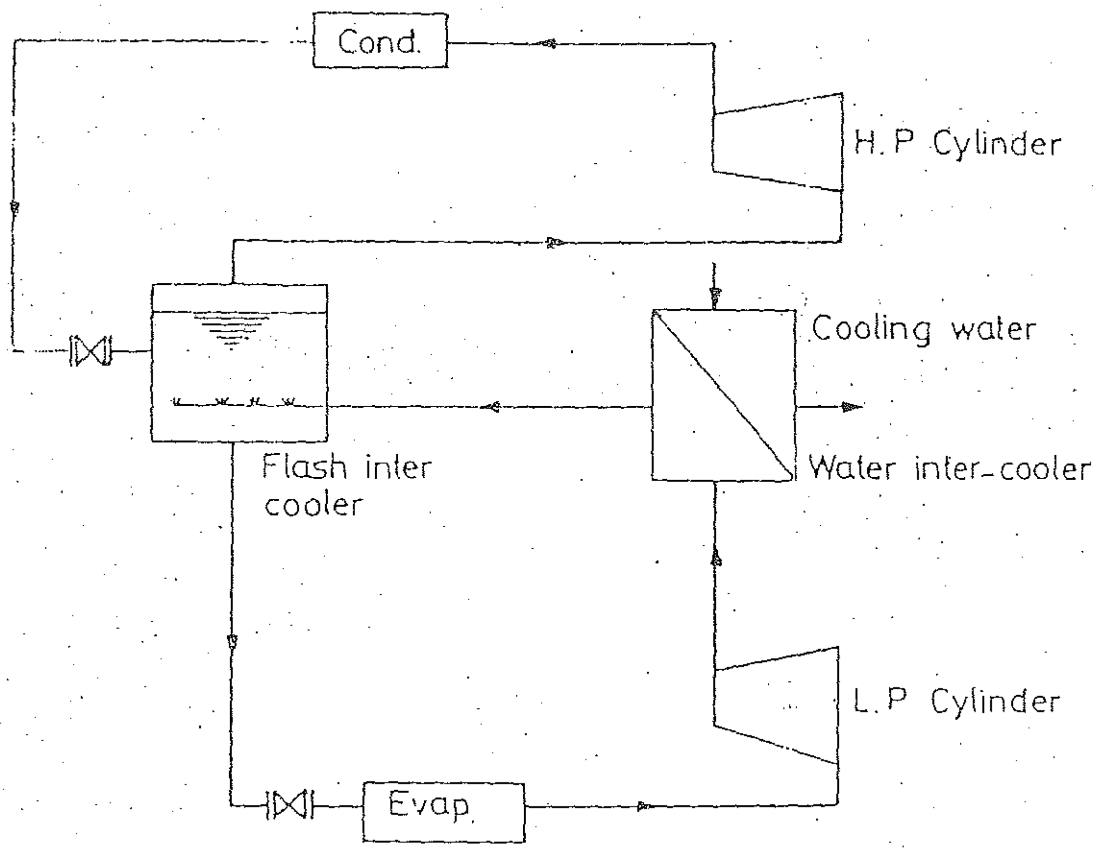
   b) If the above ammonia compressor is to be two-stage with a water intercooler, make a suitable design of the plant, and determine:
      (i) The intermediate pressure.
      (ii) The %age saving in the brake power of the compressor.

3. An ammonia plant is to be designed for an ice-factory having a daily output of 65 tons of ice under the following design conditions:
   Average temperature of water available is 22 °C,
   Temperature of ice produced is − 6 °C,
   Freezing time is 19 hours, and the estimated heat gain from the surroundings in o ice tank amounts to 10 % of the freezing load.
   a) Select suitable operating conditions for a simple ammonia system and then calculate the B.kW of the compressor, assuming a compression efficiency of 84 % and a mechanical efficiency of 90 %.
   b) If using a two-stage compressor with a water intercooler: determine the %age saving in the power of the compressor, assuming a compression efficiency of 84 % for low pressure

stage and 86 % for high pressure stage. Calculate also the %age improvement in the C.O.P of the system due to compounding.

4. Determine:
   a) The C.O.P.
   b) The maximum cycle temperature.
   c) The total piston displacement per sec. per ton, for the theoretical single stage cycle and for the cycle shown in figure.

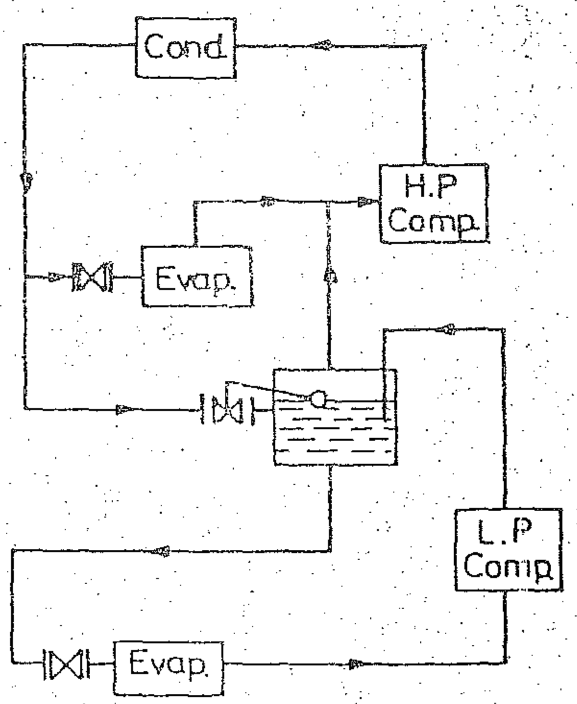
For each cycle assume an evaporating temperature of − 40 °C, condensing temperature of 38 °C, and a compressor clearance of 5 %. The refrigerant is ammonia. For the two-stage cycle, assume intermediate saturation temperature is − 11 °C, that the vapour leaves the water intercooler at 38 °C, and that the compression is isentropic.



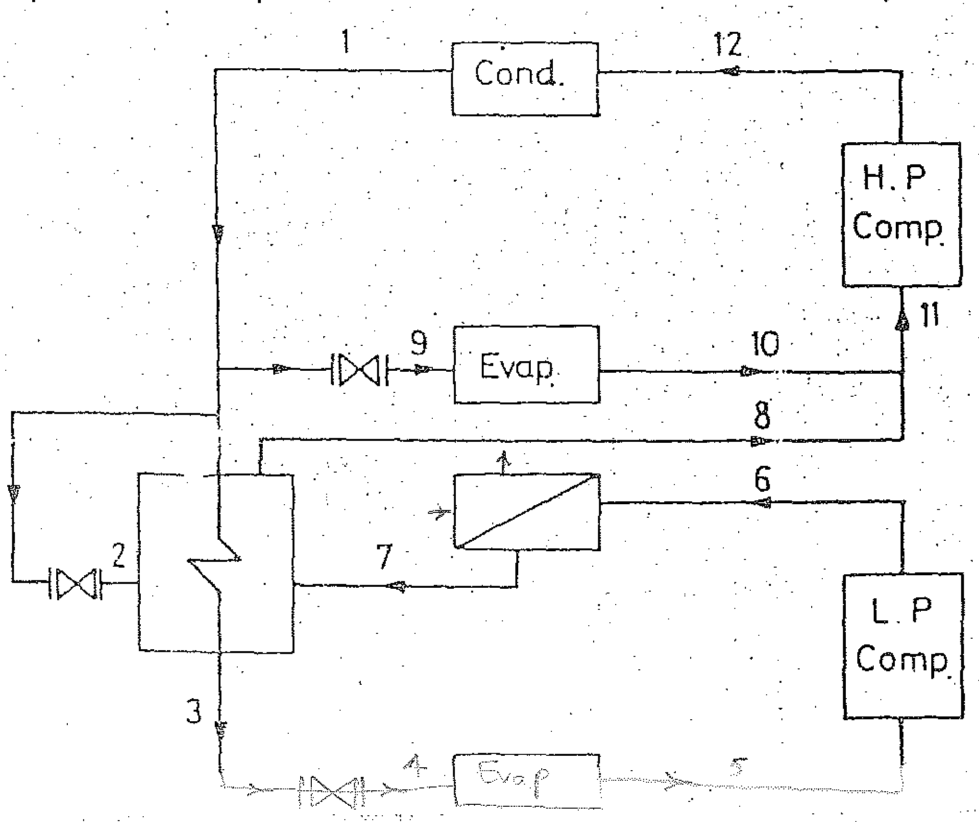
5. An industrial plant uses a R-12 system with one compressor to serve both an air-conditioning evaporator and a low temperature evaporator for process refrigeration. The air-conditioning evaporator is a liquid chiller operating with a capacity of 80 tons and is maintained at a temperature of 4.5 °C by means of a pressure regulating valve located at the outlet of the evaporator. The low pressure evaporator has a capacity of 25 tons and operates at a temperature of − 12 °C, the compressor suction pressure is the same as the pressure in the low temperature evaporator, and the condensing temperature is 32 °C. Calculate the power required by the compressor.

6. An ammonia system having a 45 ton evaporator operating at − 1.0 °C, and a 10 ton evaporator operating at − 40 °C; utilizes flash gas removal and intercooling. The condensing temperature is

32 ^{o}C. The arrangement is as shown in figure. Calculate the power required for each compressor.

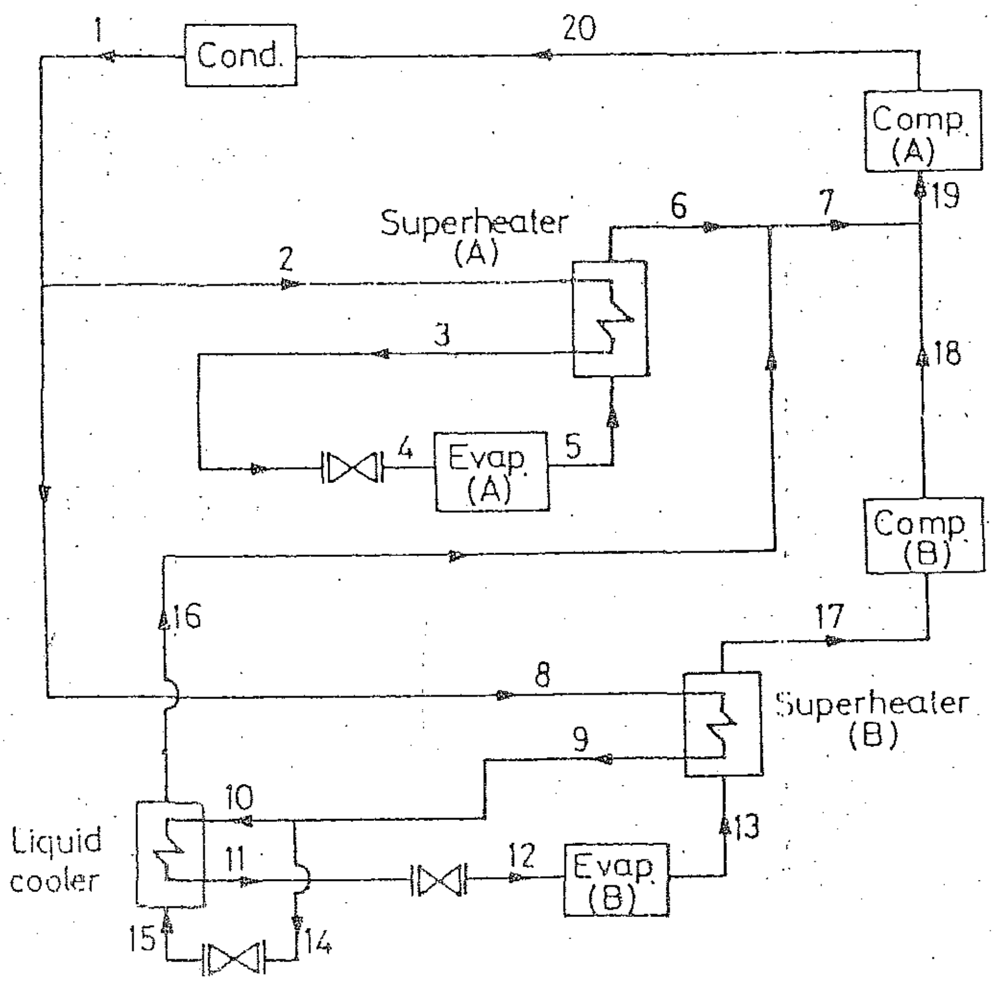


7. An ammonia vapour compression system is arranged as shown in figure. Assume isentropic compression, and the given data are:
t_1 = 32 ^{o}C, t_{10} = -7 ^{o}C, t_5 = -40 ^{o}C, t_3 = 4.5 ^{o}C, t_7 = 38 ^{o}C.
If the low pressure evaporator produces twice the capacity of the high pressure evaporator. Find the C.O.P of the cycle.

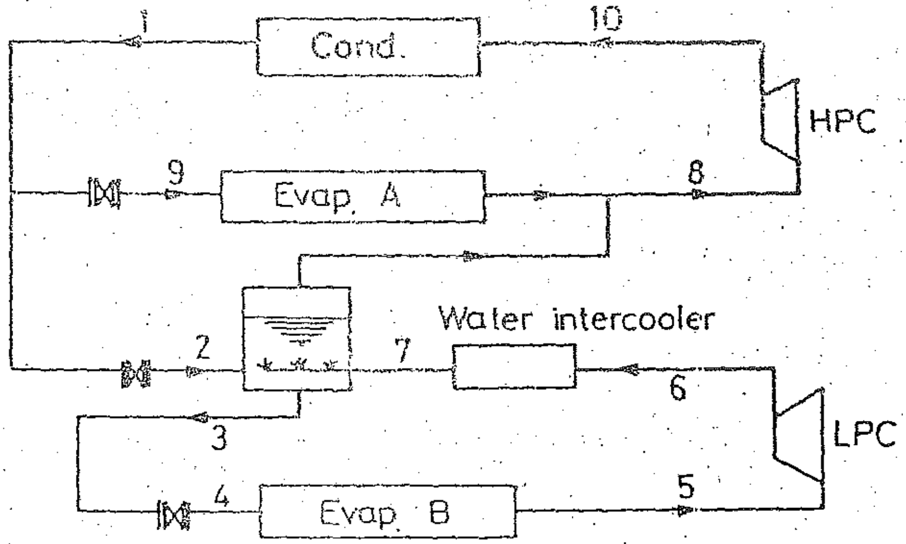


8. A cascade refrigerating system uses ammonia in the low temperature unit and freon-12 in the high temperature unit. The system develops a 50 T.R. The freon-12 system operates at -20 °C evaporation temperature, and 35 °C condensation temperature. Freon liquid is subcooled by 5 °C in the condenser. The ammonia system operates at -46 °C evaporating temperature, and -15 °C condensing temperature, which is provided by the freon-12 evaporator. Ammonia leaves the evaporator with 5 °C of superheat. There is 2 °C terminal temperature difference between ammonia and freon-12 in the evaporator/condenser.
   a) Draw the flow diagram of the cascade system.
   b) Calculate the total power required.
   c) Calculate the C.O.P of each system and that of the whole plant

9. A refrigerant-12 system is arranged as shown in figure. Assume isentropic compression and frictionless flow. The following data are given: Condensing temperature is 32 °C, evaporator (A) has a capacity of 5 tons and an evaporating temperature of -29 °C, evaporator (B) has a capacity of 10 tons and an evaporation temperature of -40 °C, and vapour leaves each evaporator in dry and saturated condition.
   t_1 = +29 °C, t_6 = -20.5 °C, t_{11} = -7 °C, t_{16} = -20.5 °C & t_{17} = -31.5 °C.
   Each compressor has 5% clearance.
   Draw schematic (P-h) and (T-s) diagrams for the cycle, and determine:
   a) The coefficient of performance of the system.
   b) The piston displacement in cu.m/sec. of each compressor.
   c) The theoretical power input to each compressor.



10. A two-stage vapour-compression ammonia refrigerator is shown in figure. Condenser pressure is 1.5 MPa. The low-temperature evaporator is kept at a pressure of 0.08 MPa while the high-temperature evaporator is at 0.4 MPa. Liquid leaving the condenser and vapour leaving each evaporator are saturated. Temperature of vapour leaving the water inetercooler is 30 ^oC. Both compression stages have an isentropic efficiency of 0.85. The condenser is water-cooled; the cooling-water temperature rises in the condenser is 9 ^oC and its flow rate is 20 cu.m/hr. The C.O.P of the cycle is 3.5. Draw a p-i diagram of the cycle and calculate the refrigeration capacity of each evaporator in tons.



11. A cold store has one above-zero room and two below-zero rooms. A two stage ammonia system is used; the arrangement of equipment is shown in figure. The high-temperature evaporator operates at 0 ^oC while the low temperature evaporators are maintained at an evaporating temperature of -30 ^oC. The refrigeration capacity is 30 tons for the high-temperature evaporator and 40 tons for each of the two low-temperature evaporators. Liquid leaving the condenser is saturated at 40 ^oC. Ammonia is cooled in the water intercooloer down to 30 ^oC. The high-pressure circulating pump circulates 0.833 kg/sec. while each of the low-pressure pumps circulates 1.056 kg/sec. Compression in both stages is considered to be adiabatic with a compression efficiency of 90 %. Plot all the points on the p-i plane then determine:

a) The state of the refrigerant returning from the air-cooling coils to each of the two surge drums.
b) The required brake power (mechanical efficiency for both stages is 90 %).
c) C.O.P of the system (neglecting pumping work).
d) Condenser duty in kW.

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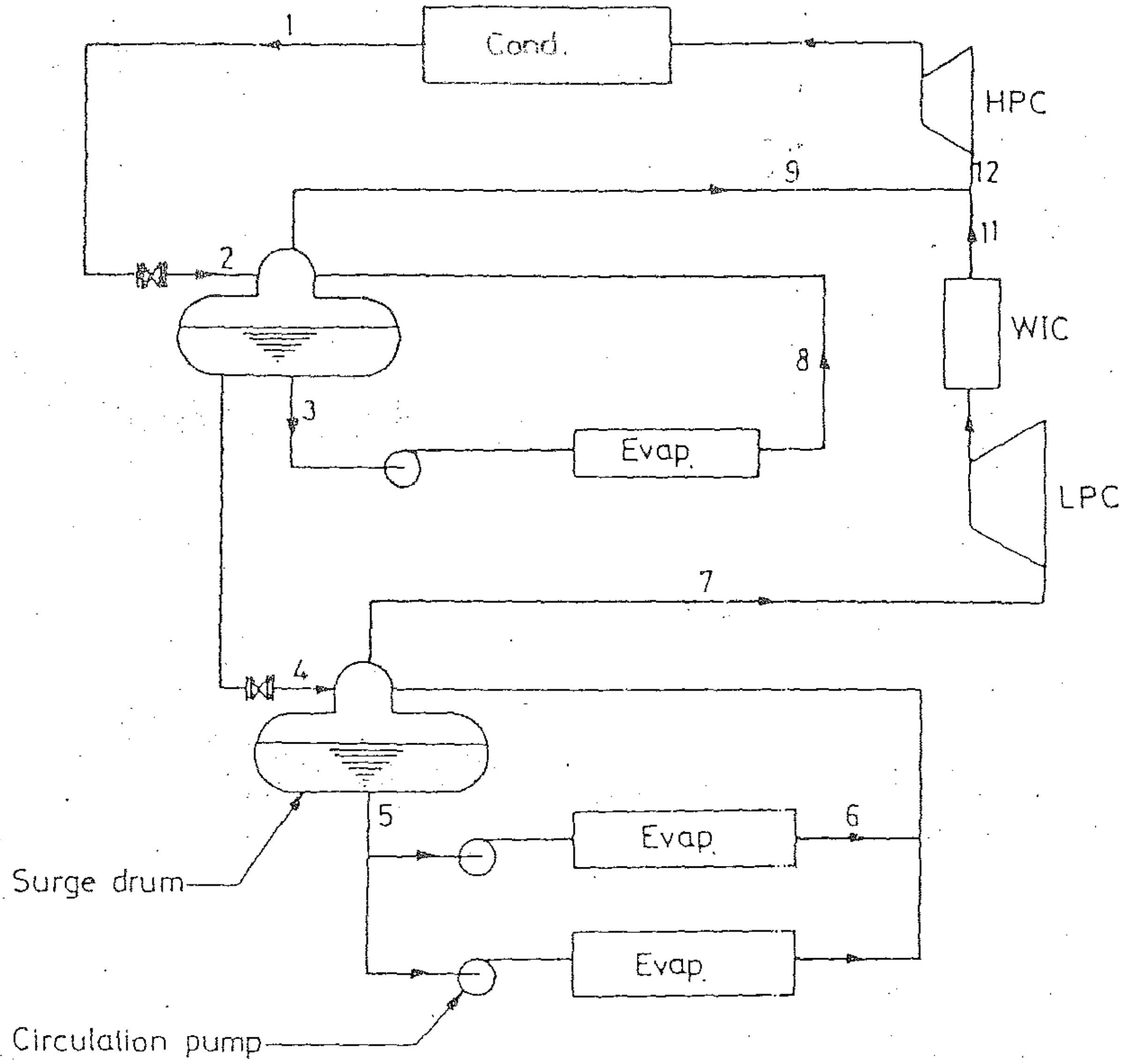
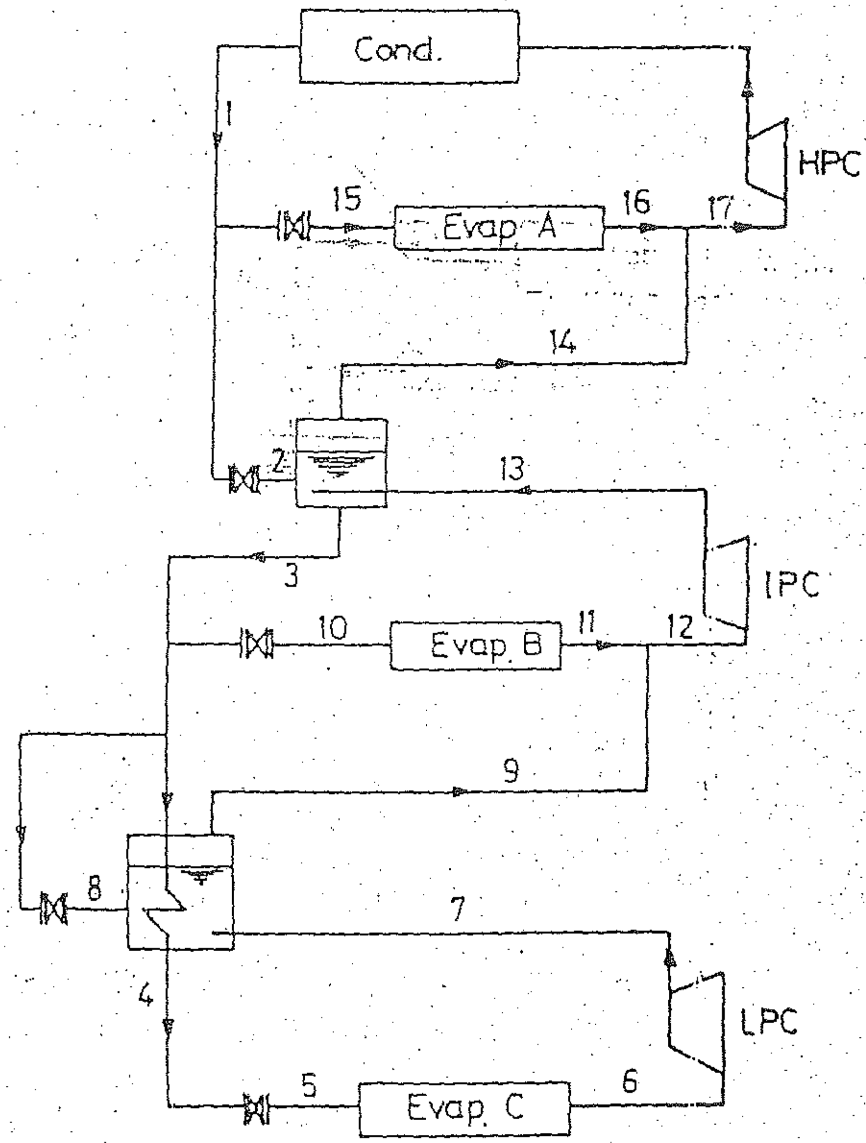


12. A three-stage ammonia refrigeration machine operates between evaporating and condensing temperatures of −70 and 40 °C. Two open-type flash intercoolers are installed; one at each of the two intermediate pressures 0.07 and 0.35 MPa. Moreover, a water intercooler is used at each of the intermediate pressures to cool the vapour down to 25 °C. Refrigerant leaves the condenser and evaporator at saturation conditions. Compression in all stages has a compression efficiency of 85 %. Draw a block diagram and plot the cycle on the p−i plane; then determine the C.O.P of the cycle. If, for some reason, the water supply to the two water intercoolers was cut off: find the percentage effect on the C.O.P.

13. A three-stage F−12 vapour-compression refrigeration system is arranged as shown in figure. The system serves an air-conditioning cooling load on evaporator A in addition to two process cooling loads of 10 and 15 tons on evaporators B and C respectively. Condensing pressure is 1 MPa and liquid is subcooled in the condenser to 30 °C. All compression processes are assumed to be

isentropic. Liquid is subcooled to −20 °C in the closed flash intercooler. The ratio of the indicated power of the high-pressure stage to that of the intermediate-pressure stage is 1.7. Evaporating pressures are 0.015, 0.08, and 0.35 MPa. The refrigerant is saturated at exit from each evaporator. Draw the p−i diagram and determine:

a) Refrigeration capacity of the air-conditioning evaporator (water chiller) in tons.
b) Total indicated power input.
c) C.O.P of the system (mechanical efficiency of all compressors is 0.9 %).
d) Approximate piston displacement (cu. m/sec.) for each compression stage if the clearance ratio is 0.04 for all compressors. Would it be advisable to interchange the places of the open and closed flash intercoolers.



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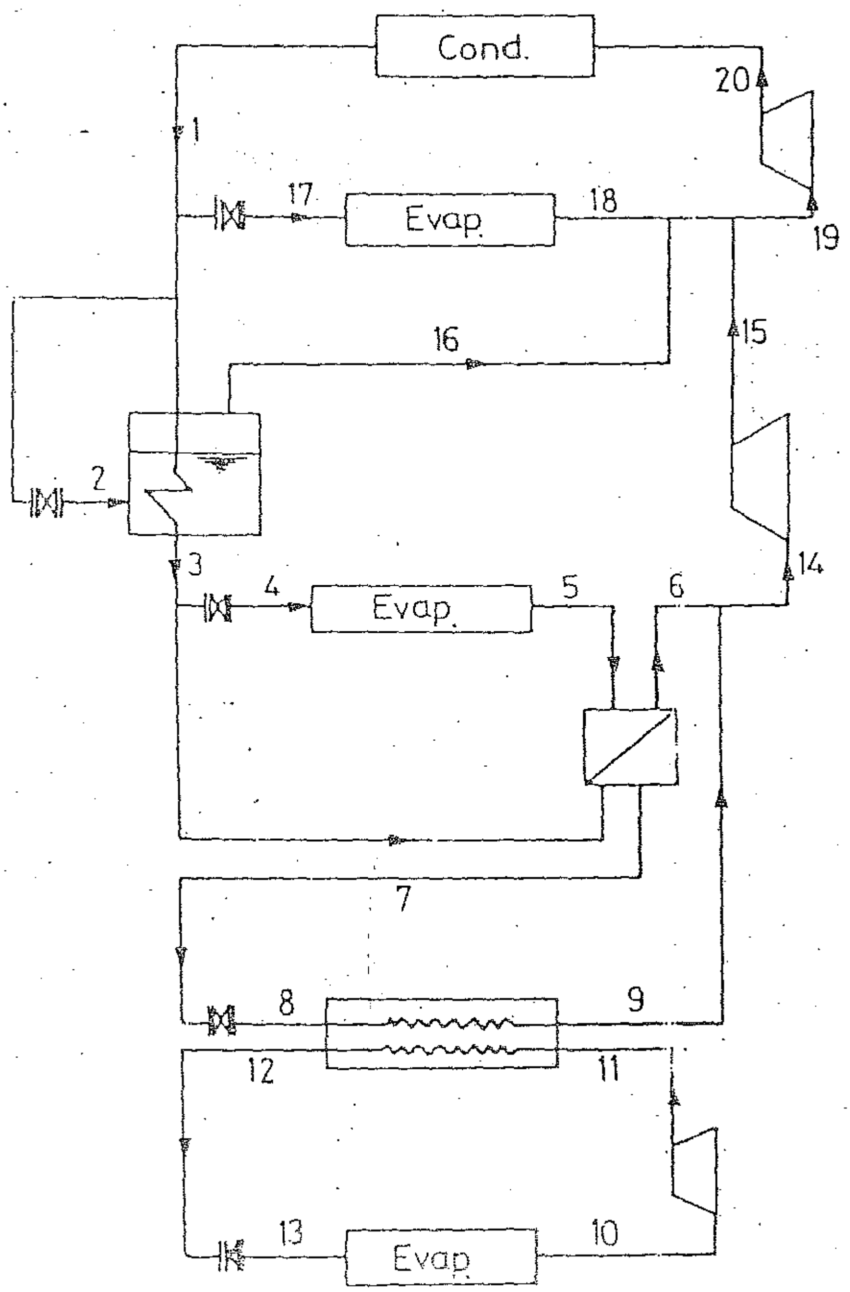
14. The refrigerants F-12 and F-13 are used in the cascade system shown in figure. The lower-temperature cycle follows a simple saturation cycle between evaporating and condensing temperatures of -80 and -20 °C. The indicated-power input to the F-13 compressor is 1.471 kW/ton. The F-12 cycle has two evaporators operating at the two pressures 0.35 and 0.08 MPa; their refrigeration capacities are 17 and 40 tons respectively. Liquid leaving the condenser is saturated at 40 °C. The liquid supplied to the expansion valve of the low-temperature evaporator is at 20 °C. Vapour leaving the high-temperature evaporator is at 10 °C. The low temperature evaporator is a flooded one; and the vapour leaving it is superheated in the liquid-to-suction heat exchanger to -20 °C. The F-12 fed to the cascade condenser has a quality at inlet x+0.1 and a temperature of -20 °C at exit. Consider compression in both stages to be isentopic. Draw the p-i diagram and determine:

a) Refrigeration capacity of the F-13 evaporator in tons.
b) Power input to the overall binary system (Z_m is 0.9 for all units).
c) C.O.P of the system.



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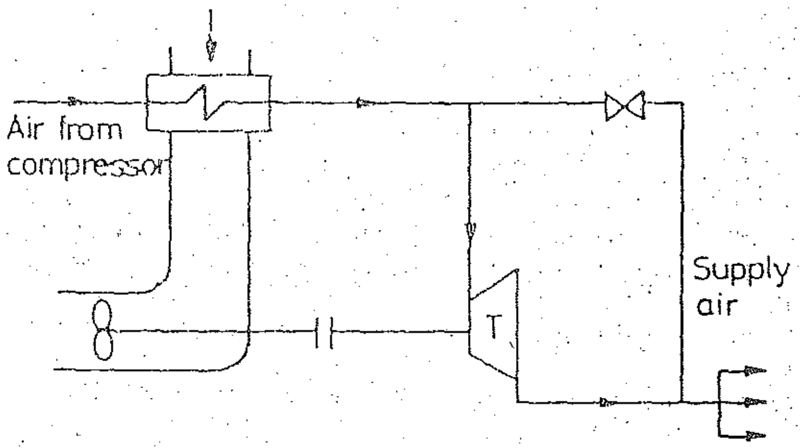
Refrigeration and Air Conditioning 4th Year (Power)

Air Refrigeration Systems

1. A closed air cycle refrigeration system produces 10 T.R. Air enters the compressor at 0.412 MPa and -7 °C & is then compressed to 1.47 MPa (n = 1.35). The temperature of the air leaving the air cooler is 28 °C. Expansion index is 1.30. Assume frictionless flow, find the C.O.P of the system and the thermodynamic relative efficiency.

2. The schematic air-cycle cooling system for a jetplane is as shown:



Assume that air is bled from the jet-engine at 330 °C and 0.69 MPa at a rate of 0.133 kg/sec. Air enters the turbine at 101 °C. For the turbine assume a polytropic exponent n = 1.20 and a mechanical efficiency of 0.8. The cabin pressure is 0.081 MPa and the air is exhausted from the cabin at 23 °C. Assume that no air is by-passed around the turbine. Determine:
a) The turbine power output.
b) The T.R. produced.

3. On a certain bootstrap unit the following performance of components is given:
Turbine efficiency 85 %, secondary compressor efficiency 77%, and secondary heat-exchanger effectiveness 90 %. The unit is designed for a cabin pressure of 0.098 MPa, an ambient air temperature 32 °C, and compressed air leaving the primary heat exchanger at 65 °C. For air to enter the cabine at 5 °C, calculate:
a) The temperature of the air leaving the secondary compressor.
b) The pressure at turbine entrance.
c) The temperature of the air entering the turbine.
d) The pressure entering the secondary compressor.

4. A boot-strap air refrigeration system is used for an air plane to give 10 ton of refrigeration. The ambient conditions are t = 5 °C and p = 0.083 MPa. The air pressure increases to 0.108 MPa

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isentropically before entering the compressor. Pressure of air bled from the main compressor is at 0.343 MPa and this air is further compressed in the secondary compressor to 0.441 MPa. The isentropic efficieny of each compressor is 90 % and that of the cooling turbine is 80 %. Heat exchanger effectiveness of the primery heat-exchanger is 60 % and that of the secondary heat exchanger is 62 %.

The airoplane cabine is maintained at 0.098 MPa and 25 °C. The cooling turbine drives the secondary compressor and its surplus power is used for the fan.

Calculate:

a) The power required to cool the cabin.

b) C.O.P of the system based on the power required by the compressor.

N.B.: air used for heat exchangers cooling is from inlet to compressor (i.e. at 0.108 MPa)

5. An air refrigeration system for a jet aeroplane operates on the simple cycle. The cockpit is maintained at 22 °C. The ambient-air pressure and temperature are 0.086 MPa and 10 °C. The stagnation pressure of the ram air is 0.126 MPa. The pressure ratio of the main compressor is 3. The plane speed is 277.8 m/sec. Temperature of the air entering the turbine is 83 °C. Pressure drop in the heat exchanger is 0.02 MPa. Compressor and turbine isentropic efficiencies are both 80 %. Pressure in the cockpit is kept at 0.098 MPa. Cocpit-cooling load is 1 ton. Draw a schematic T-s diagram of the cycle and determine:

a) Temperature of the air entering and leaving the compressor.

b) Temperature of the air supplied to the cabin.

c) Brake-power output of the turbine if its mechanical efficiency is 0.82 %.

d) Rate of heat rejection in the heat exchanger in kW.

6. The air refrigeration system of a small turbo-propelled airplane is shown in figure. Air at a pressure of 0.588 MPa is extracted from the main gas turbine compressor at a rate of 0.333 kg/sec. Temperature at inlet to the turbine is 100 °C. The turbine has a mechanical efficiency of 85 % and an expansion index of 1.2. Cabine pressure is 0.098 MPa and the maximumallowable temperature inside it is 25 °C.

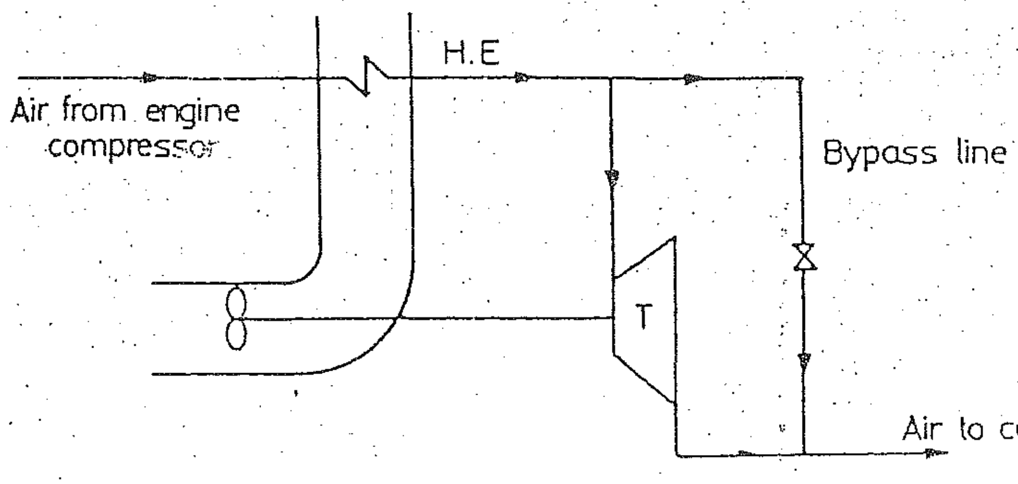
At a certain time 15 % of the air flow is bypassed around the turbine. Determine:

a) The cooling load in tons.

b) The turbine power output in kW.

c) What is the full load, in tons, that can be handled by the system under the same inside and outside conditions?

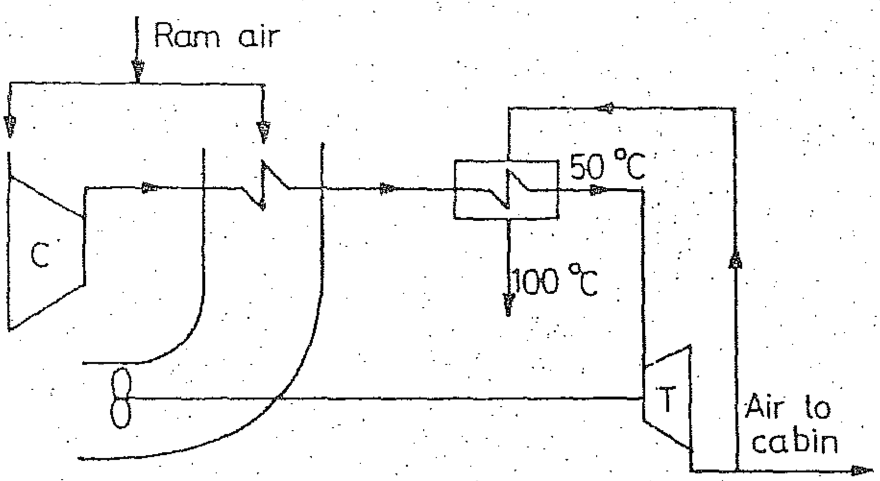
d) Bypassed fraction of air stream under half-load condition.



7. A bootstrap air refrigeration system is used to cool an aircraft cabin . The ambient-air temperature is 5 ^{o}C. The aircraft speed is 222.2 m/sec. Air is extracted from the main engine compressor at a pressure of 0.274 MPa and a rate of 0.389 kg/sec. The air is cooled in the primary heat exchanger down to 50 oC and then compressed to 0.392 MPa in the secondary compressor. The isentropic efficiencies of the turbine and secondary compressor are 0.8 and 0.84 respectively. The cabine is pressurized at a pressure of 0.098 MPa and air is exhausted from it at 22 ^{o}C. The mechanical efficiencies of the turbine and the secondary compressor are 0.84 and 0.87 respectively. Determine:
a) The refrigeration load in tons.
b) The effectiveness of the secondary heat exchanger.

8. The reduced-ambient air refrigeration system is used in an aircraft flying at a cruising speed of 416.7 m/sec. The ambient conditions are 0.078 MPa and 5 ^{o}C. The ram-compression process is assumed to be isentropic. The air leaving the compressor is cooled to 100 ^{o}C in the heat exchanger. The pressure ratio of the main gas-turbine compressor is 3. The pressure drop in the outlets supplying air to the cabine is 0.01 MPa. The cabin is maintained at 0.098 MPa and 22 ^{o}C. The adiabatic efficiencies of the compressor and the two turbines are 88 % and 86 % respectively. The cabin-cooling load is 10 tons. Draw a schematic T-s diagram of the cycle and determine:
a) The shaft power delivered to the fan if the mechanical efficiencies of both turbines are 88 %.
b) Mass flow rate of ram air through the heat exchanger, in kg/sec., if its temperature at exit is limited to 80 ^{o}C.
c) Effectiveness of the heat exchanger.
d) C.O.P of the cycle and its efficiency ratio.

9. The regenerative air-refrigeration system of a jet plane is shown in figure. The cabine is pressurized to 0.098 MPa and is



maintained at 25 ^{o}C. The cabin-cooling load is 30 tons. The ambient conditions are 0.083 MPa and 5 ^{o}C. The ram air pressure is increased from 0.083 to 0.118 MPa, due to isentropic stagnation against the plane body, before being admitted to both compressor and primary heat-exchanger. Air is delivered from the compressor at 0.471 MPa. The primary heat-exchanger has an effectiveness of 0.6. The air is further cooled in the secondary (or regenerative) heat-exchanger down to 50 ^{o}C while on the other side the

cooling air is heated to 100 ^{o}C before being discharged. The isentropic efficiency of compressor and turbine is 0.9 and 0.8 respectively. Draw a neat T-s diagram of the cycle and calculate:

a) The percentage of the total air flow used for regenerative cooling.
b) The power necessary to carry the refrigeration load.
c) The C.O.P of the cycle and its relative efficiency.

10. A regenerative system is used for cooling the cabin of an aircraft travelling at a speed of 305.6 m/sec. The ambient-air temperature is 4 ^{o}C. Ram air pressure increases due to irreversible stagnation against the aeroplane. Air is extracted from the engine compressor at 150 ^{o}C. Compression and expansion, in compressor and turbine, are both polytropic and have the indices 1.3 and 1.2 respectively. The effectivenesses of the ram-air and regenerative heat exchangers are 0.6 and 0.77 respectively. Considerable pressure drop takes place in each of the two heat exchangers; and air is admitted to the turbine at 0.294 MPa. The cabin is maintained at 0.098 MPa and 25 ^{o}C. The cold air used for regenerative cooling represents 49 % of the total mass flow rate through the turbine. The indicated power necessary to meet the cabin-cooling load is 183.9 kW. Draw a flow diagram and a schematic T-s diagram and calculate:

a) The cooling load in tons.
b) Temperature of the air discharged to the atmosphere from the regenerative heat exchanger.

11. A simple system is used for cooling a high-speed aeroplane. A bypass line around the turbine is used to cope with part loads. The cabin is kept at 0.098 MPa and 25 ^{o}C. Air delivered by the compressor to the heat exchanger is at 148 ^{o}C. The heat-exchanger effectiveness is 65 %. Air is supplied to the turbine at 87 ^{o}C. Compression and expansion indices are 1.2 and 1.3 respectively.
When the cabin-cooling load is 75 % of the full load the C.O.P of the cycle is 0.1024. Draw a flow and a T-s diagrams then calculate:

a) Pressure at inlet to the turbine.
b) Cruising speed of the airplane if the ambient-air temperature is 3 ^{o}C.

CAIRO UNIVERSITY
FACULTY OF ENGINEERING
Mechanical Power Engineering Department

Refrigeration and Air Conditioning 4th Year (Power)

Air Conditioning

1. A certain building is to be air-conditioned in summer. The followin data is given:
   Outside air condition is, 38 °C d.b.t and 25 °C w.b.t.
   Inside design condition is, 26 °C d.b.t and 50 % R.H.
   Estimated heat gain from the building is, 17.445 kW.
   Electric lighting and machines load is, 40 kW.
   Total number of persons equals 100; each gives 0.0814 kW of sensibl heat, and 0.11 kW of latent heat.
   Fresh air to be allowed per person equals 20 cu.m/hr.
   Determine:
   a) The sensible heat factor.
   b) The total amount of conditioned air to be circulated.
   c) The cooling capacity of the air conditioner in T.R.
   d) The cooling coil dew point.

2. A summer air conditioning apparatus is used for cooling an dehumidification is to maintain 21 °C d.b.t and 70 % R.H. in print shop which has an estimated sensible heat gain of 58.15 kW an latent heat gain of 17.445 kW under design condition. Assuming tha all the air is recirculated, find out:
   a) Sensible heat ratio.
   b) The apparatus dew point temperature.
   c) The rate of flow of recirculated air per sec.
   d) The tons of refrigeration, of the refrigerating machine.
   Compute the refrigeration capacity in case of using 50 % of fres air at 39 °C d.b.t and 27 °C w.b.t and 50 % of returned air fro the shop.

3. A theatre is to be air-conditioned for the following summe operating conditions:
   Outside condition is, 38 °C d.b.t and 25 °C w.b.t.
   Inside condition is, 26 °C d.b.t and 50 % relative humidity.
   Total number of persons is, 1000.
   Lighting inside theatre amounts to 10 kW.
   Total sensible heat gain from building amounts 430.31 kW.
   Sensible heat gain from persons equals 0.0814 kW per person.
   Latent heat gain from persons equals 0.105 kW per person.
   Fresh air to be allowed is, 30 cubic meters per hour per person.
   Conditioned air leaving the cooling coil at 90 % relative humidity.
   Make a neat diagram of the complete air-conditioning plant for th theatre.
   Show also the air cycle on the psychrometric chart. Then determin the following:
   a) The sensible heat factor.
   b) The cooling coil mean temperature, and efficiency.
   c) The amount of air to be circulated inside the theatre, i cu.m/hr.
   d) The cooling capacity of the plant in tons of refrigeration.

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* All mass flow rates are in kg dry air / unit time.

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4. The following data is given for an air conditioning plant;
Outside air condition is, 38 °C d.b.t and 26 °C w.b.t.
Inside room condition is, 25 °C d.b.t and 55 % R.H.
Fresh air supply equals 0.0150 kg/sec.
Room sensible load is, 43.961 kW.
Room latent load is, 13.956 kW.
Show the air cycle on the psychrometric chart and determine:
a) The temperature to which the air must be cooled and dehumidified.
b) The total quantity of conditioned air to be supplied, and the plant capacity.

5. An air conditioning plant for a restaurant operates under the following conditions:
Outside air at 38 °C d.b.t and 23 °C w.b.t.
Inside conditions are 25 °C d.b.t and 50 % relative humidity.
Total heat load for the restaurant = 45.59 kW.
Air leaves the cooling coil at 10 °C d.b.t and 90 % R.H.
The conditioner is fitted with a by-pass for mixing a certain part of return air with air leaving the cooling coil to obtain a mixture at 15 °C d.b.t, then the mixture is heated by a heating coil up to 20 °C d.b.t before admission into the restaurant. Assuming equal weights of fresh air to return entering the cooling coil;
a) Draw a flow diagram of the plant and represent the cycle on the psychrometric chart, give a slectch of the cycle.
b) Calculate the sensible heat factor.
c) Calculate the amount of air circulated into the restaurant.
d) Find the amount of fresh air taken in the coil in cu.m/sec., and the ratio of return air which by-passed the cooling coil.
e) Find the refrigerating capacity of the cooling coil in tons of refrigeration and the capacity of the heater in kW.

6. A restaurant is to be air conditioned during the summer. The following data is given:
Outside air temperatures are; 35 °C d.b.t and 25 °C w.b.t.
Inside conditions are; 22 °C d.b.t and 55 % R.H.
Heat gain from the building = 29.075 kW
Lighting load = 8 kW.
People in the restaurant amounts 500; each gives 0.116 kW sensible heat and 0.093 kW latent heat.
Food: 0.056 kg/sec. producing 50.2 kJ/kg sensible heat and 16.7 kJ/kg latent heat.
Fresh air equals 27 % of circulated air.
If the air leaves the cooling coil at 90 % R.H, find out:
The room sensible heat factor, apparatus dew point, and the amount of air to be circulated in cu.m/sec.
Sketch the air cycle on the psychrometric chart.

7. A club is to be air conditioned in summer for the following conditions:
Dry-bulb outside air temperature = 35 °C.
Wet-bulb outside air temperature = 26 °C.
Dry-bulb inside air temperature = 25 °C.
Inside air relative humidity = 50 %.
Heat load from the building = 23.26 kW.
Number of peaple inside building = 500; each gives 0.093 kW Sensible heat and 0.0872 W latent heat.
Total lighting load = 10 kW.
Fresh air allowed per person = 20 cu.m/hr.
The temperature of supply air is 10 °C below the dry-bulb temperature inside the conditioned space and air leaves the cooler at 90 % R.H.
Make a sketch of the psychrometric cycle and calculate:
a) The fan capacity in m^3/sec.

b) Cooling capacity of the cooler in T.R.
c) Reheater capacity in kW.

8. A space is maintained at 24 °C d.b.t and 50 % relative humidity. The space sensible heat factor is 0.757. No outdoor air is required for ventilation. The space is served by an air-cooling coil which delivers air to the space at a relative humidity of 80 %. Determine:
a) The apparatus dew-point temperature and the coil bypass factor.
b) The rate of air circulated in kg/sec. and m^3/sec per ton of space sensible load.
c) The rate of water drainage from the coil, in liter/sec, for a space sensible load of 5 tons.

9. A theatre is air-conditioned in summer. The inside conditions are maintained at 25 °C d.b.t and 50 % R.H. Outside conditions are 35 °C d.b.t and 60 % R.H. Conditioned air is supplied to the theater at 16 °C d.b.t. Heat gain through walls is 116.3 kW, and heat emitted from electrical equipment and lighting is 58.15 kw. Number of persons is 300; each gives 0.0814 kW of sensible heat and 0.064 kW of latent heat. Necessary supply of fresh outdoor air is 14 m^3/hr per person. Sketch the psychrometric diagram and calculate:
a) The sensible heat ratio.
b) Amount of conditioned air admitted into the theater in kg/sec. and m^3/sec.
c) Bypass factor and effective surface temperature of the cooling coil.
d) Capacity of refrigerating machine in tons.
e) Amount of water drained from the cooling coil in kg/sec.

10. A building is maintained at 26 °C d.b.t and 50 % R.H while the outside conditions are 35 °C d.b.t and 20 °C dew-point temperature. Conditioned air is supplied to the building at a rate of 4.083 kg/sec. The building has a rate of sensible heat gain of 26.377 kW and a rate of moisture gain of 1.89×10^{-3} kg/sec. Outdoor air is introduced, for ventilation, at a rate of 0.833 m^3/sec. Some of the recirculated (return) air is bypassed around the cooling coil. The air which passes through the coil is brought to 90 % R.H. Draw a schematic flow diagram of the air conditioning system and determine:
a) The state of the air supplied to the building.
b) The amount of the retun air bypassed around the coil in kg/sec.
c) The apparatus dew-point temperature and the coil efficiency.

11. A building in a hot arid location is air-conditioned in summer by a simple evaporative-cooling system. The inside conditions are kept at 28 °C d.b.t and 21 °C w.b.t while outdoor air is at 40 °C d.b.t and 10 % R.H. The building has a rate of latent-heat gain of 3.541 kW and a sensible heat factor of 0.797. Equal masses of recirculated and fresh air are mixed then passed through the air washer. Determine:
a) The mass flow rate of cooled air admitted to the building.
b) The water-spray temperature in the washer.
Compare the water consumption with that in case of using 100 percent outdoor air.

12. An auditorium is maintained at 25 °C d.b.t and 50 % R.H. The outside conditions are 40 °C d.b.t and 27 °C w.b.t. The air conditioning system is shown in figure. At a certain part-load condition the sensible and latent loads are 116.3 and 79.342 kW respectively. Conditioned air is supplied to the auditorium at 20 °C. The apparatus dew point of the cooling coil is 5 °C and the coil efficiency is 70 %. The mass of fresh air is 50 % of the air mass

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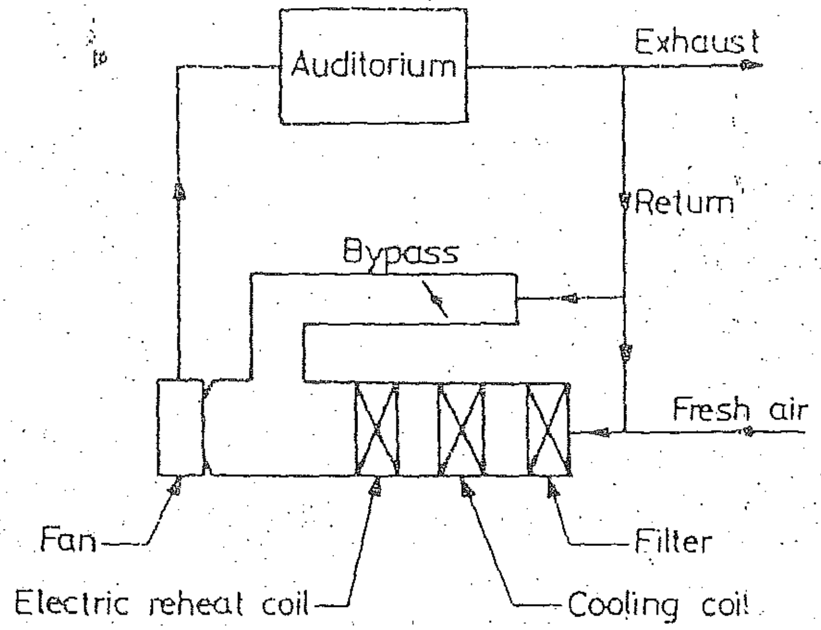


passing through the cooling and reheating coils. Calculate:

a) The sensible heat ratio.
b) The amount of conditioned air supplied to the auditorium in kg/sec. and m^3/sec.
c) The amount of return air bypassed around the coils in kg/sec.
d) The amount of fresh air in kg/sec.
e) The amount of water drained from the cooling coil in liter/sec.
f) The refrigerating capacity of the cooling coil in tons.
g) The heating capacity of the reheating coil in kW.

Plot the cycle on the psychrometric chart and calculate:

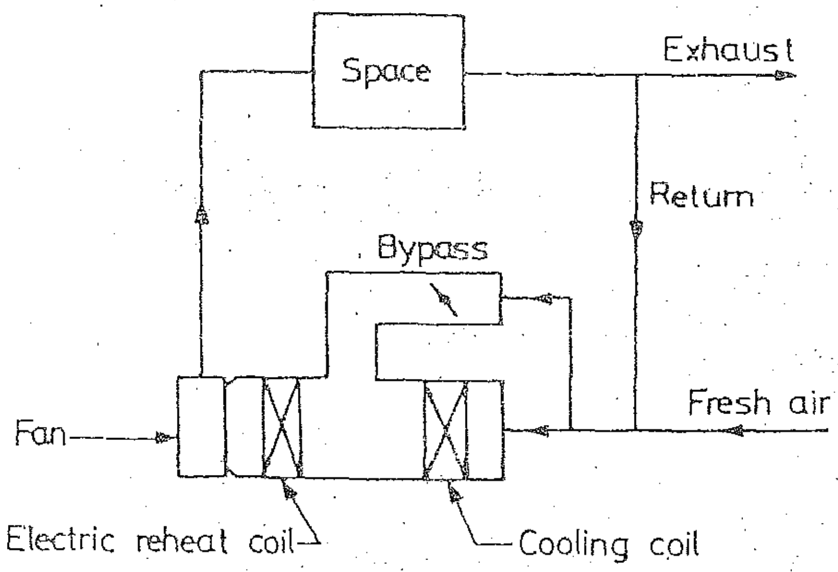
a) The quantity of air bypassed around the cooling coil in kg/sec. and m^3/sec.

b) The amount of condensate removed from the cooling coil in kg/sec.

c) The refrigerating capacity of the cooling coil in tons.

d) The electric power supply to the reheating coil in kW.

14. A space is maintained at 25 °C d.b.t and 50 % R.H. The air conditioning system is shown in figure. The outside conditions are



40 °C d.b.t and 27 °C w.b.t. Conditioned air supplied to the space is at 18 °C d.b.t and 14 °C w.b.t. Fresh outside air represents 30 % of the total amount of air flow to the space. The cooling coil has a refrigeration capacity of 50 tons; the apparatus dew point is 5 °C and the coil efficiency is 80 %.

Draw the cycle on the psychrometric chart and determine:

a) The percentage of air flow bypassed around the cooling coil.

b) The heating capacity of the reheating coil in kW.

c) The sensible and latent loads of the space in kW.

15. A Space is to be maintained at 26 °C d.b.t and 50 % relative humidity in summer. The air conditioning plant comprises a cooling coil followed by an electric reheating coil. The rates of sensible and latent heat gain to the space are 74.665 and 41.635 kW respectively. Air leaves the cooling coil at 14 °C d.b.t and 90 % R.H. The outside conditions are 40 °C d.b.t and 28 °C w.b.t. The effective surface temperature of the cooling coil is 11.5 °C.

Determine:

a) The state and rate of mass flow, in kg/sec., of the conditioned air supplied to the space.

b) The power of the reheating coil in kW.

c) The amount of fresh air introduced for ventilation in m^3/sec.

If the relative humidity of the air supplied to the space is limited to a maximum of 90 %, is it possible to serve this load with a cooling coil only? If it is, what should be the effective surface temperature of this coil? If the coil efficiency is the same as in the first case, would it be necessary to bypass a fraction of the air flow around the coil, and what should this fraction be?

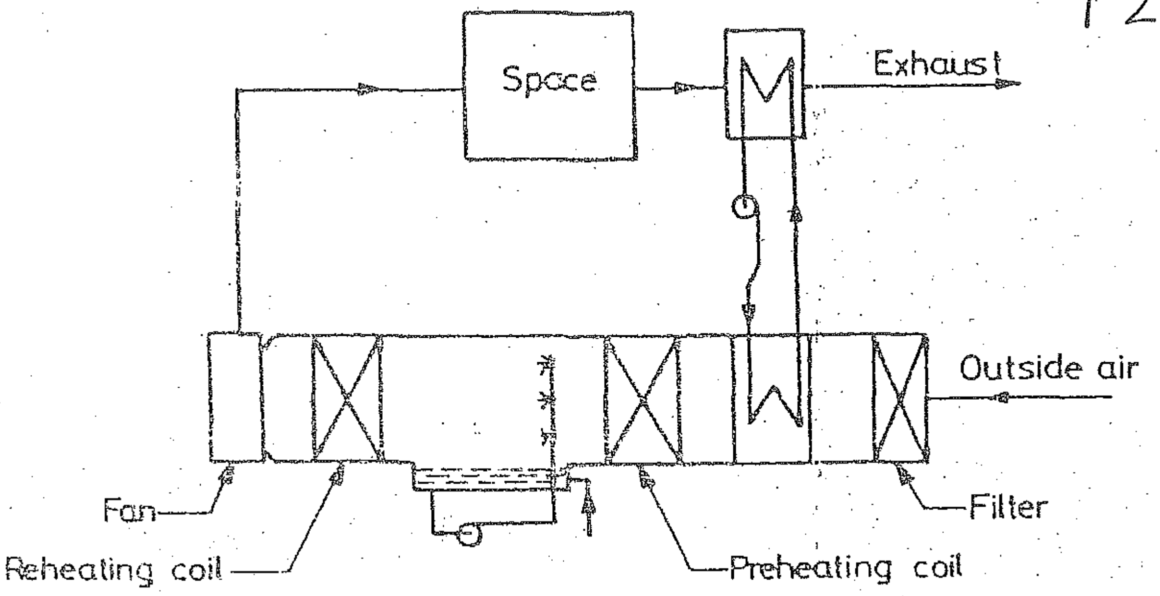
Compare the required refrigeration capacity in the two cases.

16. A space is air-conditioned in winter. The air conditioning plant comprises a preheating coil, an air washer, and a reheating coil. The rates of sensible and latent heat loss from the space are 232.(and 58.939 kW respectively. The space is maintained at 21 °C d.b.t and 14 °C w.b.t. Air is supplied to the space at 38 °C. Outdoor air is saturated at 5 °C. The mass flow rate of ventilation air is 50 % of that admitted to the space. The air washer has an efficiency of 50 %. Draw a schematic flow diagram of the air conditioning system, plot the cycle on the psychrometric chart, then determine:
a) The flow rate of conditioned air to the space in m^3/sec.
b) The spray-water temperature.
c) Rate of addition of makeup water to the sump of the washer in kg/sec.
d) Rate of heat addition to the air in each of the heaters in kW.

17. An interior space of a building is to be maintained at 22 °C during winter. The space has a net rate of sensible heat gain of 17.445 kW; moisture gain is neglegible. There is no need for ventilation in this space. However, and in accordance with an energy-saving policy, the space is cooled by mixing outdoor air with recirculated air and admitting the mixture to the space. Air supplied to the space should be at 12 °C. On a particular day, the outside conditions are 5 °C d.b.t and 90 % R.H.
a) Determine the amount of air supplied to the space in kg/sec.
b) Find the percentage of the supply air which is outdoor air.
c) Assuming 0.735kW brake power per ton as the compressor power requirement for a mechanical refrigeration system, estimate the daily saving in operating cost realized by the above-mentioned system as compared to a complete-recirculation system with mechanical refrigeration. The space is occupied 8 hours per day, and electricity costs 30 millimes per kWh.

18. A building is air-conditioned in winter. The inside conditions are kept at 25 °C d.b.t and 50 % R.H. while the outside conditions are 5 °C d.b.t and 90 % R.H. The building has a rate of sensible heat loss of 174.45 kW and a rate of latent heat gain of 95.366 kW. The ventilation requirement of the building is 10.972 m^3/sec. of fresh air. The mixture of fresh and recirculated air is preheated, passed through an air washer with bypass control, then reheated before being admitted to the building. The washer (humidification) efficiency is 75 % and the temperature of the spray water is 15 °C. Conditioned air is supplied to the building at a condition such that the diffusion temperature is 10 °C. Draw a schematic flow diagram of the air conditioning system and determine:
a) Flow rate of air to the building in kg/sec and m^3/sec.
b) Temperature to which air is heated in the preheating coil.
c) The fraction bypassed around the air washer.
d) Rate of addition of makeup water to the washer in kg/sec.
e) The rate of heat addition to the air in each heating coil in kW.

19. A space is maintained at 23 °C d.b.t and 50 % R.H. during winter. The outside conditions are 6 °C d.b.t and 5 °C w.b.t. The space is air-conditioned by the system shown in figure with waste-heat recovery and 100 % outdoor air. The sensible heat loss from the space is 104.67 kW and the sensible heat factor is 0.7975. Conditioned air is supplied to the space with a diffusion temperature of 17 °C. Air enters the reheating coil at a temperature of 21 °C. Air is exhausted at 15 °C. Plot the cycle on the psychrometric chart and determine:
a) Flow rate of conditioned air in kg/sec. and m^3/sec.
b) Rate of heat addition to air in the preheating coil in kW.
c) Percentage saving in heating load realized by the waste-heat



recovery system.
d) The washer efficiency.
e) Water consumption of the air washer in kg/sec.

20. A weaving hall is maintained at 30 °C d.b.t and 70 % R.H. The outside conditions are 40 °C d.b.t and 26 °C w.b.t. The total heat gain of the hall is 116.3 kW with a sensible heat factor of 0.8. Conditioned air is admitted to the hall at 25 °C. The fresh outside air represents 25 % of the total mass flow rate of conditioned air. The air conditioning system comprises a cooling coil and an air washer. Determine:
a) Flow rate of conditioned air in m^3/sec.
b) Temperature of air leaving the cooling coil.
c) Refrigeration capacity of the cooling coil in tons.
d) Washer efficiency.

21. A drying chamber is used for drying dates from moisture content of 45 % to 10 % on the wet basis and at a rate of 2 tons of dates per hour. Air leaving the drying room is at 23 °C d.b.t and 90 % R.H and air is admitted to the room at 49 °C. The outside air (winter conditions are 5 °C d.b.t and 70 % R.H. Determine:
a) The percentage of air recirculated.
b) The heating capacity of the heater in kW.

CAIRO UNIVERSITY
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Mechanical Power Engineering Department

Refrigeration and Air Conditioning — 4th Year (Power)

Condensers and Evaporators

1. A refrigerator is to serve a cooling load of 16 ton. The machine condenser is air cooled and the heat rejection ratio is 1.244. The condenser has an air-side area of 210 m^2 and the overall coefficient of heat transfer based on this area is 37 $W/m^2.K$. The condenser has a face area of 2.2 m^2 and the face velocity of air is 3 m/s. Density of ambient air is 1.15 kg/m^3. If the condensing temperature is to be limited to 55 ^oC, what is the maximum allowable ambient temperature?

2. A direct-expansion finned-coil evaporator has the following areas: refrigerant side 15 m^2, air-side prime area 13.5 m^2, and air-side fin (extended) area 144 m^2. The boiling heat-transfer coefficient inside the tubes is 1300 $W/m^2.K$ and the air-side coefficient is 48 $W/m^2.K$. The fin efficiency is 64%. Neglecting the thermal resistance of tubes, determine the value of the (UA) product for this air cooler.

3. A flooded shell-and-tube evaporator is used to cool a liquid, which flows inside the tubes, from 15 to 5 ^oC. The tubes are made of copper with inside and outside diameters of 8 and 9.53 mm. Liquid-flow velocity inside tubes is 2 m/s. The refrigerant saturation temperature and the average boiling heat-transfer coefficient on the shell side are -1 ^oC and 800 $W/m^2.K$. Neglect the tube thermal resistance and determine the total required length of tubes per ton of the refrigeration load. [Properties of liquid at 10 ^oC are μ=0.0013 Pa.s, ρ=1050 kg/m^3, k=0.57 W/m.K, and C=4250 J/kg.K]

4- A shell-and-tube condenser has an overall coefficient of heat transfer of 800 $W/m^2.K$ based on the water-side area (inner area). The water pressure drop, through the condenser is 50 kPa. Under this operating condition, 40% of the overall thermal

resistance is on the water side. If the water-flow rate is doubled, what will be the new value of the overall coefficient and the new water-pressure drop?

5. Calculate the mean condensing heat-transfer coefficient when R.12 condenses on the outside surface of plain horizontal tubes in a shell-and-tube water-cooled condenser. The outside diameter of the tubes is 19 mm. There are five vertical rows of tubes with 2, 3, 4, 3, and 2 tubes per row. The saturation temperature inside the condenser is 52 ^oC and the average temperature of the tube surface is 44 ^oC. [At 52^oC saturation temperature, the liquid density and the latent heat of vaporization of R.12 are 1202.36 kg/m^3 and 120 kJ/kg]

6- The manufacturer of a water-cooled shell-and-tube ammonia condenser guarantees the overall coefficient of heat transfer under operating conditions to be 990 $W/m^2.K$ (based on the water-side area). What should be the value of the overall coefficient when the condenser leaves the factory?

7- The following results were recorded during the testing of a shell-and-tube ammonia condenser with water flowing inside the tubes

U_o $W/m^2.K$	2070	1930	865	1570	2300	1760	1360	1130
V m/s	0.975	0.853	0.244	0.61	1.22	0.731	0.488	0.366

where U_o is the overall heat-transfer coefficient based on the outer area and V is the water velocity in tubes. Condenser tubes are plain with inside and outside diameters of 46 and 51 mm and a thermal conductivity of 60 W/m.K. Determine:

i - The condensing heat transfer coefficient.

ii - The heat-transfer coefficient on the water side at a water flow velocity of 0.45 m/s.

iii- The overall coefficient U_i at a water velocity of 0.75 m/s.

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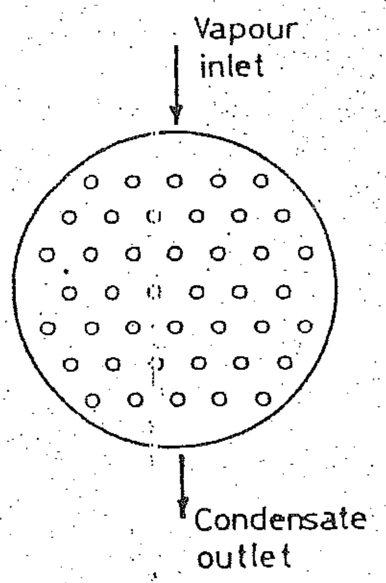
8 - A dry-expansion shell-and-tube water chiller has refrigerant tubes of 31 mm inside diameter and 35 mm outside diameter. The tubes are made of copper with a thermal conductivity of 370 W/m.K. The chiller was tested at two different values of water-flow rate through the shell. The measured overall heat-transfer coefficient, based on inside area, was 700 and 805 $W/m^2.K$ for water-flow rates of 5 and 8 liters/s respectively. Estimate the average value of the boiling heat-transfer coefficient inside the tubes. Find, also, the heat-transfer coefficient on the outside surface of tubes at a water-flow rate of 10 liters/s. (Solve without drawing)

9 - A water-cooled shell-and-tube condenser is to be designed for a R.22 refrigeration system to meet an air-conditioning cooling load of 22.75 ton. The condensing temperature is 45 ^oC and the heat rejection ratio is 1.27 (hermetic compressor). Water from a cooling tower enters the condenser (on the tube side) at 30 ^oC and leaves at 35 ^oC. The condenser has two passes and a total number of tubes of 42 arranged as shown in figure. Plain copper tubes are used with inside and outside diameters of 14 and 16 mm. Thermal conductivity of copper is 390 W/m.K. A fouling factor of 0.000176 $m^2.K/W$ is to be taken into consideration. At 45 ^oC the liquid density and the latent heat of vaporization of R.22 are 1109 kg/m^3 and 160.9 kJ/kg respectively. [The following properties may be taken for water at 32.5 ^oC: ρ=995 kg/m^3, μ=0.000773 Pa.s, C=4.19 kJ/kg.K, and k=0.617 W/m.K]



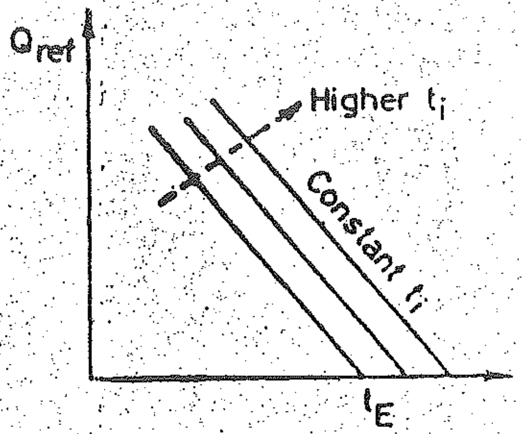
Determine the distance between the two tube plates and the total required length of tubes.

10- In a water-chilling evaporator, if the water flow rate and heat transfer coefficients are constant, prove that the evaporator performance can be represented by the straight lines in figure.

Q_{ref} - Refrigeration capacity, kW.

t_i - Incoming-water temperature, °C.

t_E - Evaporating temperature, °C.



CAIRO UNIVERSITY
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Refrigeration and Air Conditioning 4th Year (Power)

Cooling Towers and Compressors

1- A refrigeration system carries a refrigeration load of 30 tons. The heat rejection ratio is 1.27. The system is equipped with a water-cooled condenser connected to a cooling tower which has an approach of 5 ^{o}C. The wet-bulb temperature of ambient air is 25 ^{o}C. Water leaves the condenser at 37 ^{o}C. The head loss in the cooling water circuit is 4 m. The cooling water pump has an efficiency of 75 % and is directly driven by an electric motor having an efficiency of 70 %. Calculate the power input to the driving motor. If the temperature of the warm water leaving the condenser drops 1 ^{o}C on its way to the tower, what is the range of the cooling tower?

2- In a water-cooling tower the rate of water evaporation is 0.5 kg/s. The maximum permissible solid concentration in the tower is 1800 ppm. Brackish water, from a well, having a salinity of 1000 ppm is used for makeup. It is proposed to install a water treatment plant to reduce the salinity of supply water down to 700 ppm. What is the expected percentage saving in water consumption?

3- A small refrigerating machine working with R-12 has a capacity of 1 ton and is operating between the pressure limits of 1 and 0.1 MPa. Saturated liquid is fed to the expansion valve and refrigerant leaving the evaporator to the compressor is at -21 ^{o}C. The machine is fitted with a rotary compressor of the rolling-piston type rotating at 900 rpm. The roller diameter and the cylinder length are 0.75 and 1.1 times the cylinder diameter respectively. Calculate the three main dimensions of the compressor.

4- An ammonia refrigeration system operating between the pressure limits of 1.5 and 0.25 MPa is equipped with a flooded evaporator and a rotating vane compressor. Liquid leaving the condenser is saturated. The four-vane compressor rotates at 1200 rpm and its characteristic volume is 190 cm^3. Calculate the refrigeration capacity in tons.

5- A two-cylinder R-12 compressor has a bore and a stroke of 5.55 and 5 cm respectively and a clearance factor of 4 %. It is required to prepare a rating table for this compressor, listing the refrigeration capacity versus the evaporating temperature, based on the following conditions: simple satuartion cycle, 40 ^oC condensing temperature, clearance volumetric effeciency, and a speed of 950 rpm. Calculate the two refrigeration capacities that will be quoted against the two evaporating temperatures -10 and 10 ^oC. (γ=1.13)

6- Catalogue data for a Freon-12 reciprocating compressor show that the compressor produces 20 tons when integrated in a refrigeration cycle having the following characteristics: Evaporating temperature -5 ^oC, condensing temperature 40 ^oC, liquid fed to the expansion valve is saturated, and suction temperature is 15 ^oC.

i - The evaporator is a dry expansion one directly adjacent to the compressor. Calculate the refrigeration capacity of this compressor if the suction temperature becomes 0 ^oC.

ii- Solve the same problem if the evaporator is a remote flooded evaporator connected to the compressor via a long suction line.

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CAIRO UNIVERSITY
FACULTY OF ENGINEERING
Mechanical Power Engineering Department
Refrigeration and Air Conditioning 4th Year (Power)

Expansion Devices

1- In a Refrigerant-12 refrigeration system, the expanstion valve is located at an elevation of 8 m above the condenser. The water-cooled condenser operates at a condensing temperature of 37 ^oC. The pressure drop, due to friction, along the liquid line is 0.27 kp/cm^2. If the liquid line is assumed to be perfectly insulated, estimate the degrees of subcooling that must be achieved in the condenser in order to ensure that vapour would not be formed before the expansion valve.

2- A Refrigerant-12 thermostatic expansion valve uses the same refrigerant as a power fluid. The valve is designed to fade out at a pressure of 4.447 kp/cm^2. The volume of the power-fluid system (bulb and connecting tube) is 15 cm^3. Determine the mass of Refrigerant-12 contained in the power system.

3- A small Refrigerant-12 refrigerator has a compressor running with a piston displacement of 0.1 m^3/min. The compressor clearance factor is 5 %. Under all conditions, the vapour leaving the evaporator is assumed to be saturated and the compression process is considered to have an index n=1.11. The refrigerator is fitted with a capillary tube the mass-flow characteristics of which may be practically expressed by

$$\dot{m} = 0.015 \times t_{cond.} + 1.1 - 0.24\, p_{ev.}$$

where $\dot{m}$ is the mass flow rate in kg/min, $t_{cond.}$ is the condensing temperature ^oC, and $p_{ev.}$ is the evaporator pressure kp/cm^2.

Under normal running conditions, the condensing temperature is 40 ^oC. Estimate the evaporation temperature and the rate of mass flow through the evaporator.

After a period of operation, with incompetent maintenance, and due to external fouling of the air-cooled condenser the air circulation across the condenser was retarded and the condensing temperature rose to 60 ^oC. What would be the evaporating temrperature under this condition and what would be

the rate of mass flow through the evaporator?
Give an approximate estimate of the refrigeration capacity, in tons, in each of the two cases.

4- A Refrigerant-12 evaporator is fed by a float valve which has an orifice opening of 0.25 cm^2 at wide-open position. The evaporating and condensing temperatures are -10 and 35 ^oC. Liquid leaving the condenser is saturated. The coefficient of discharge of the orifice is 0.84. Estimate the maximum refrigeration capacity under these conditions. (Use the average value of liquid density).

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Refrigeration and Air Conditioning 4th Year (Power)

Absorption Refrigeration, Steam-jet refrigeration and thermo electric cooling

1- What is the COP of an ideal heat-operated refrigeration cycle that receives the energizing heat from a solar collector at a temperature of 70 ^oC, performs refrigeration at 15 ^oC, and rejects heat to atmosphere at a temperature of 35 ^oC.

2- A simple LiBr-water absorption cycle operates at the following temperatures: generator, 105 ^oC, condenser, 35 ^oC, evaporator, 5 ^oC, and absorber, 30 ^oC. The flow rate of solution delivered by the pump is 0.4 kg/s.

i - What are the mass flow rates of solution returning from the generator to the absorber and of the refrigerant?

ii- What are the rates of heat transfer at each of the components, and the COP?

3- In an absorption cycle with heat exchanger, the solution temperature leaving the heat exchanger and entering the generator is 48 ^oC, generator temperature = 100 ^oC, condenser temperature = 40 ^oC, absorber temperature = 30 ^oC, evaporator temperature = 10 ^oC and the flow rate through the pump = 0.6 kg/s. What are the rates of heat transfer at the generator and the temperature of the solution entering the absorber.

4- In an absorption cycle with heat exchanger the solution leaving the heat exchanger and returning to the absorber is at a temperature of 60 ^oC. The generatore temperature is 95 ^oC. What is the minimum condensing temperature permitted in order to prevent crystallization in the system?

5- In a steam-jet refrigeration, the following data apply: motive steam pressure = 700 kPa, condition of motive steam at entry to nozzle is dry saturated, flash chamber (evaporator) water temperature = 4 ^{o}C, temperature of make-up water to flash chamber = 17 ^{o}C, pressure in the condenser = 5 kPa, nozzle efficiency = 90 %, entrainment efficiency = 60 %, compression effeciency (including shock wave) = 70 %. Determine:

i - Mass flow rate of steam per kg of flash vapour generated.

ii - Refrigeration capacity per kg of flash vapour.

iii- Mass flow rate of motive steam per kW of refrigeration.

iv - Volume flow of vapour leaving the flash chamber per kW of refrigeration.

Assume the quality of steam at entry to thermo-compressor as 0.92.

6- A thermoelectric cooling system is to be designed to maintain a small insulated chamber at 4 ^{o}C when the ambient temperature is 32 ^{o}C. The estimated load is 29 W. Each thermoelectric element will be cylindrical with a length of 1.25 cm and a diamemetr of 1 cm. Thermoelectric properties are:

		p	n
α	V/k	170×10^{-6}	-190×10^{-6}
ρ	Ω cm	0.001	0.0008
k	W/cm K	0.02	0.02

Determine:

i - Number of couples required.

ii - Rate of heat rejection from the heat dissipator.

iii- The COP.

iv - The overall voltage drop and watts capacity of the d.c. power source.

Assume the cold junction at -1 ^{o}C and the warm junction at 38 ^{o}C, and the electrical resistance of the leads and junctions = 10 % of the elements'resistance and design for maximum refrigeration capacity.